TMT
THIRTY METER TELESCOPE

JPL
Jet Propulsion Laboratory
California Institute of Technology

Optical Performance Prediction of the Thirty Meter Telescope after Initial Alignment Using Optical Modeling

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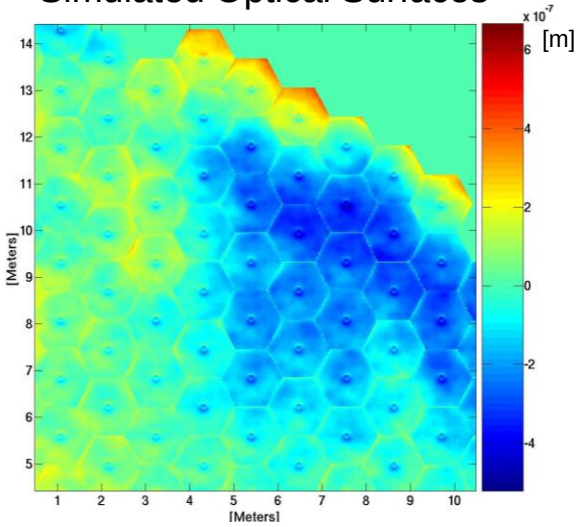
Thirty Meter Telescope

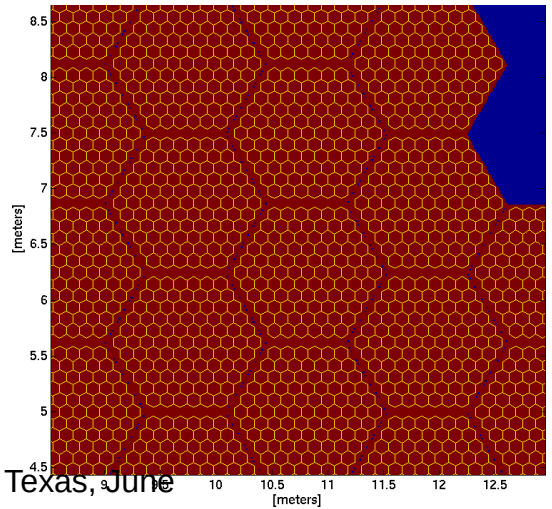
Introduction

- Optical modeling team at JPL/TMT SE perform TMT optical analysis.
- Motivation is to capture the overall optical performance after the initial TMT alignment.
  - Consider all known errors
  - Execute the potential initial alignment plan
  - Estimate the initially aligned TMT performance & Compare to TMT budget
  - Study different alignment scenarios

Simulated Optical Surfaces



Simulated APS SH-WFS

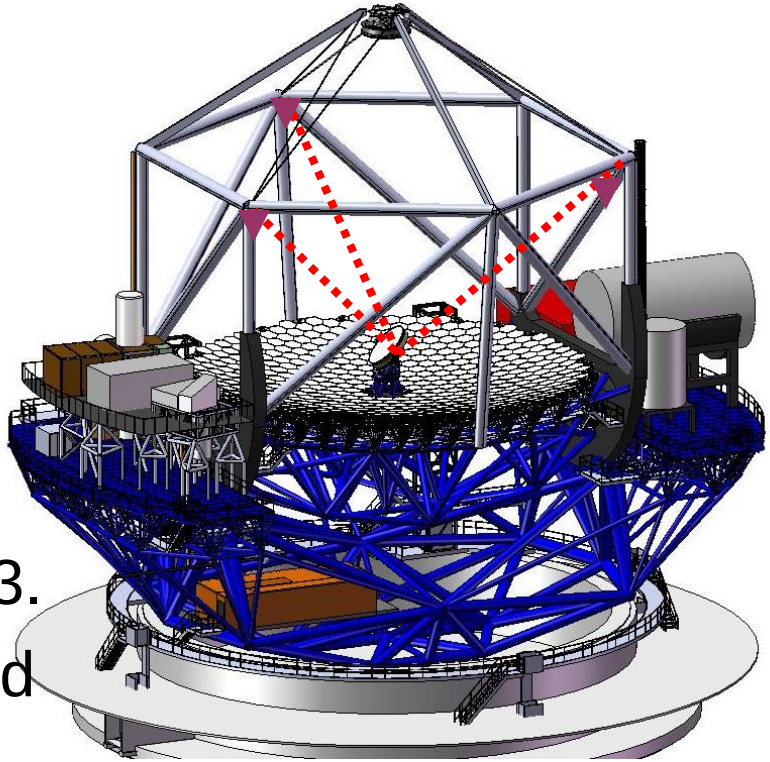


Outline

- Overview of Contributing Instruments
  - Global metrology system (GMS)
  - Alignment and Phasing system (APS)
  - M1 Control System (M1CS)
- TMT modeling before alignment.
- A potential alignment plan & Assumptions
- Key study results
- Summary & Future work

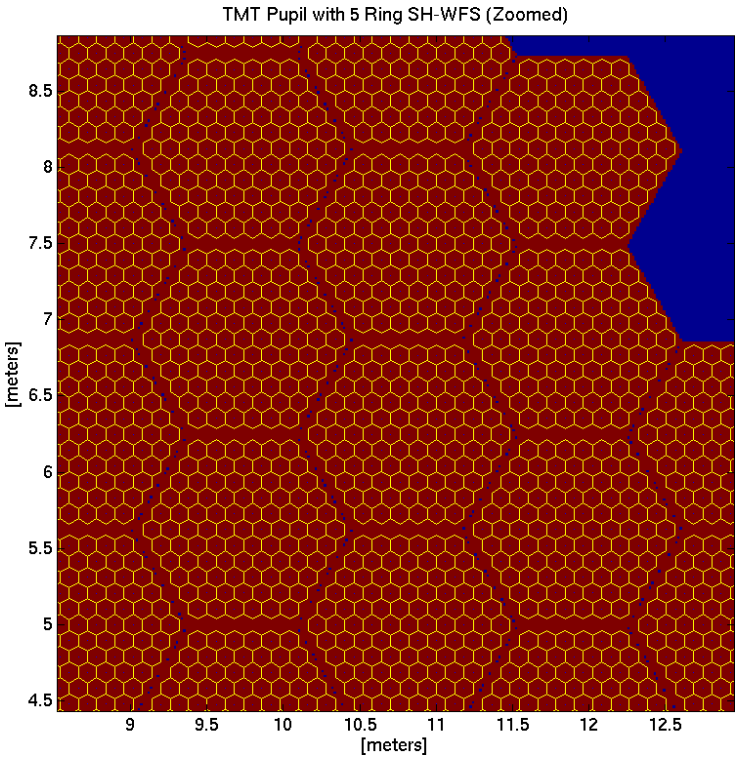
Global Metrology System (GMS)

- GMS consists of:
  - Three laser trackers
  - Targets on M1 (outer and inner segment only), M2, M3 and instruments.
- Perform coarse alignment of local coordinate systems and optics.
- Provide a LUT for zenith angles.
- Less than 50urad/20 um for M2/M3.
- Modeling assumption: GMS is used for M2, M3, M1 local coordinate (Not individual segment or instrument)



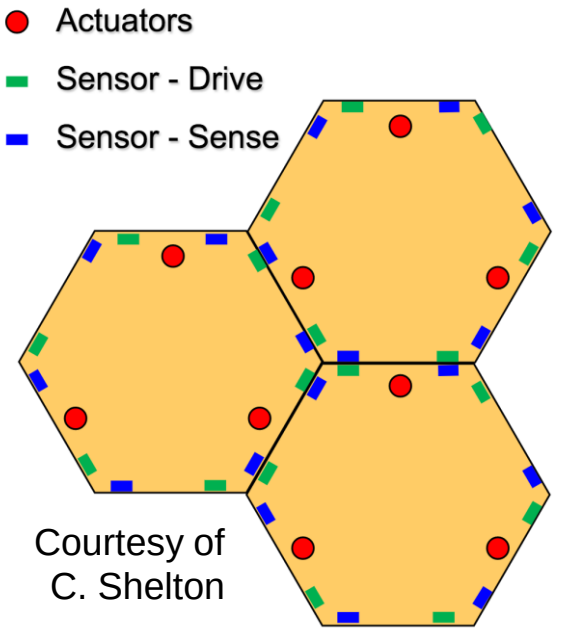
Alignment & Phasing System (APS)

- APS consists of:
  - SH-WFS & Pupil masks
- Perform fine alignment of M1 segment, M2, and M3.
- Provide a LUT for each zenith angle.
- Accuracy is limited by Seeing.
- Heritage design from PCS/Keck.
- Modeling Assumption:
  - 5 ring-subaperture SH-WFE
  - 10 SVD WH control
  - 240 second exposure (r_0= 200 mm)
  - 6 nm segment phasing accuracy



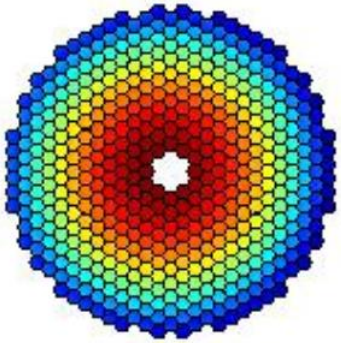
M1 Control System (M1CS)

- M1CS consists of:
  - 2772 edge sensors
  - Three actuators per segment.
- Perform relative alignment of M1 out-of-plane segment motion.
- Accuracy is limited by sensor noise.
- Modeling Assumption:
  - Perfect M1CS
  - Analysis is done elsewhere independently.

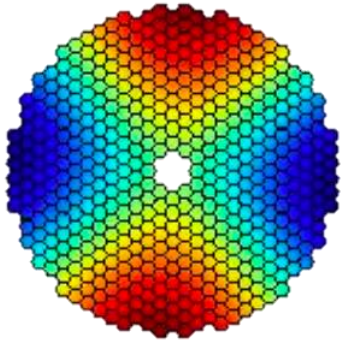


Courtesy of C. Shelton

SVD Mode 0



SVD Mode 4



TMT Error Budget Summary

THIRTY METER TELESCOPE

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Snap Shot of TMT
Observatory Architecture Doc. (OAD)

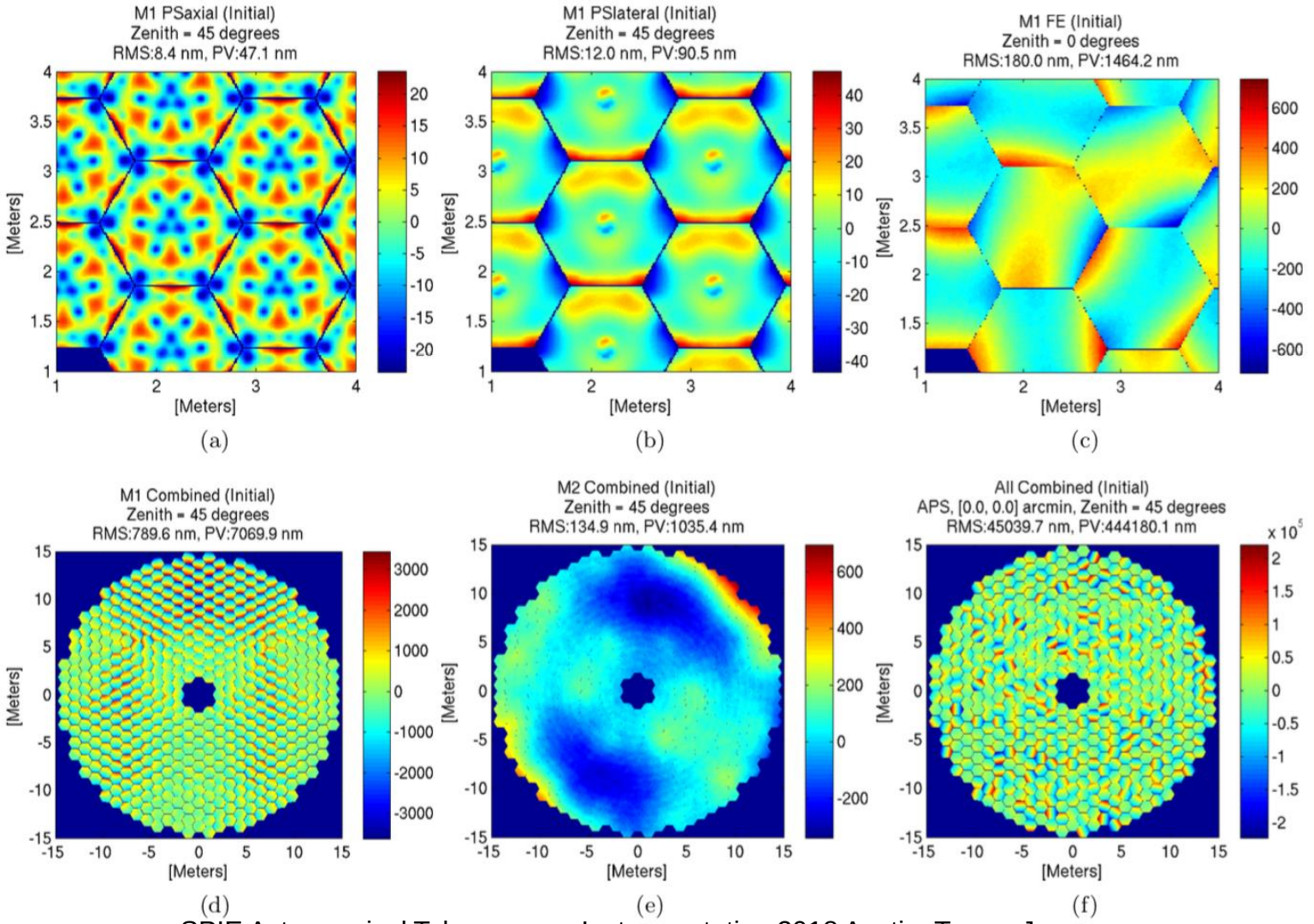
Thermal (mirror and dome) seeing (TS)		Thermal Seeing	TS
Optical surface shapes			
	M1 shape		
		Segment residual figure error (SRFE)	SRFE
		Segment thermal distortion (STD)	STD
		Segment support print through (SSPT)	SSPT
		Segment drift errors (SDE)	SDE
		Segment in-plane displacement (SIPD)	SIPD
		M1 gravity induced, thermal and installation errors	SIPD-M1
		STR gravity errors	SIPD-STR
		Segment out-of-plane displacement (SOPD)	SOPD
		Segment dynamic residuals (SDDR)	SDDR
	M2 shape		
		M2 residual figure error (M2RFE)	M2RFE
		M2 thermal distortion (M2TD)	M2TD
		M2 shape drift errors (M2SDE)	M2SDE
		M2 support print through (M2SPT)	M2SPT
		M2 dynamic shape residual (M2DSR)	M2DSR
	M3 shape		
		M3 residual figure error (M3RFE)	M3RFE
		M3 thermal distortion (M3TD)	M3TD
		M3 shape drift errors (M3SDE)	M3SDE
		M3 support print through (M3SPT)	M3SPT
		M3 dynamic shape residual (M3DSR)	M3DSR
	Wavefront Sensing		
		M1 warping harness wavefront measurement error	WFSWH
		M1 segment phasing wavefront measurement error	WFSSP
		Low order wavefront measurement error	WFSLO
		M1 segment tip/tilt wavefront measurement error	WFSTT
Optical alignment			
		Telescope collimation errors (COLL)	COLL
		Dynamic alignment (control noise)	CN
		Guider Noise	CN-INS
		Mount Control Noise	CN-STR
		M2 jitter	CN-M2
		M3 jitter	CN-M3
		Wind residual (WJ)	WJ
		STR wind residual	WJ-STR
		M2 wind residual	WJ-M2
		M3 wind residual	WJ-M3
		Vibration residual (VJ)	VJ
		Dynamic blur residual (DBLUR)	DBLUR
Contingency		Contingency	

Highlight of OAD budget

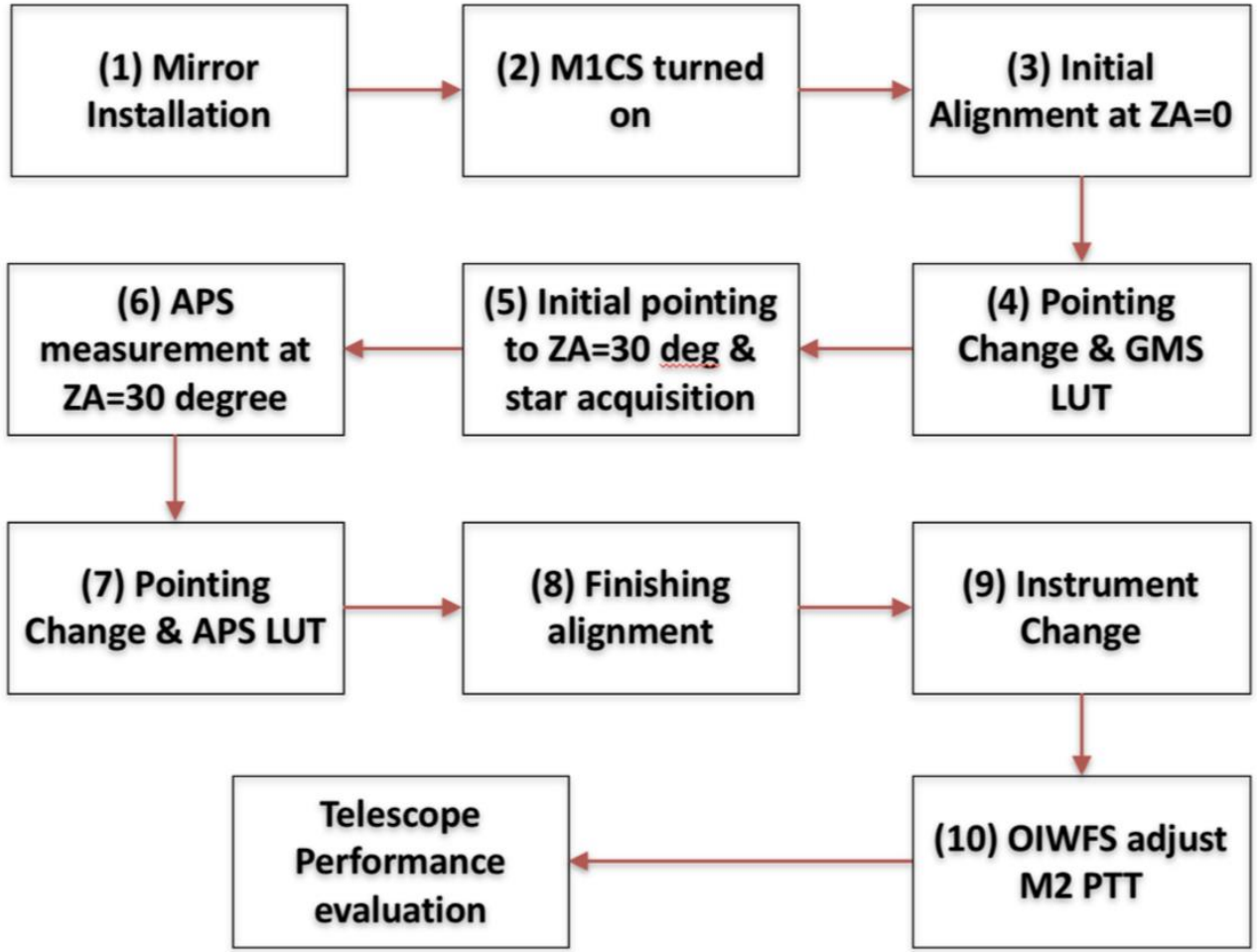
Total PSSN Budget	0.85
Optical surface errors	0.8701
Thermal & Dome seeing	0.9801
Optical alignment errors	0.9881
Contingency	1.0037

- Most up-to-dated optical surface errors included for this study.
- The budget sum of all modeled errors is **0.90327**.

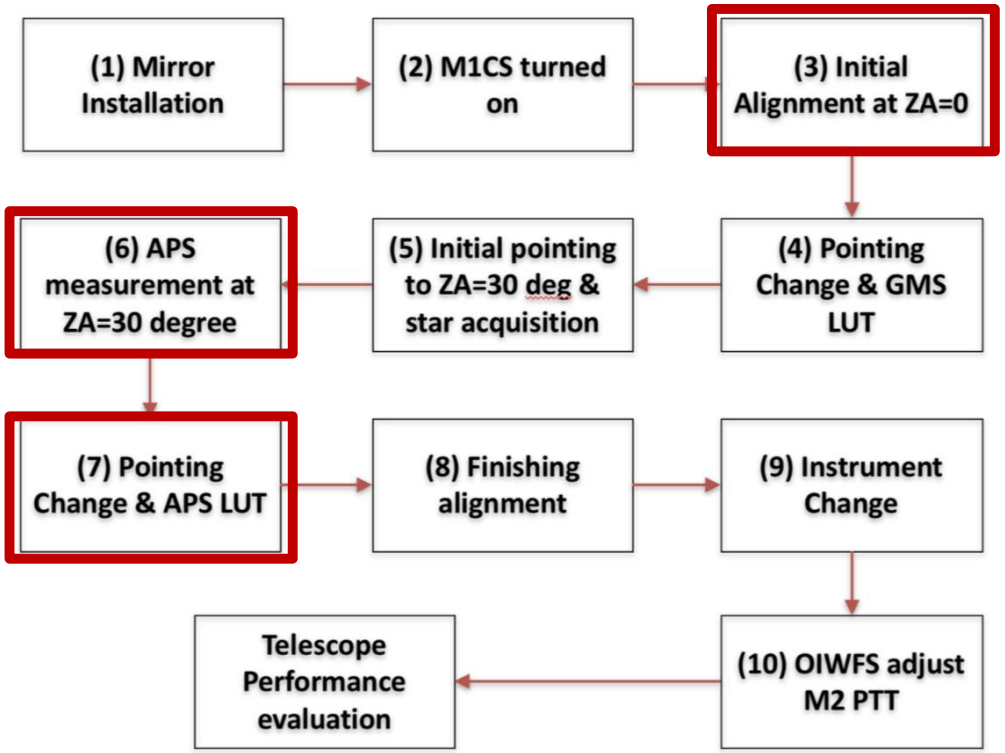
Example OPDs before alignment



Alignment Overview

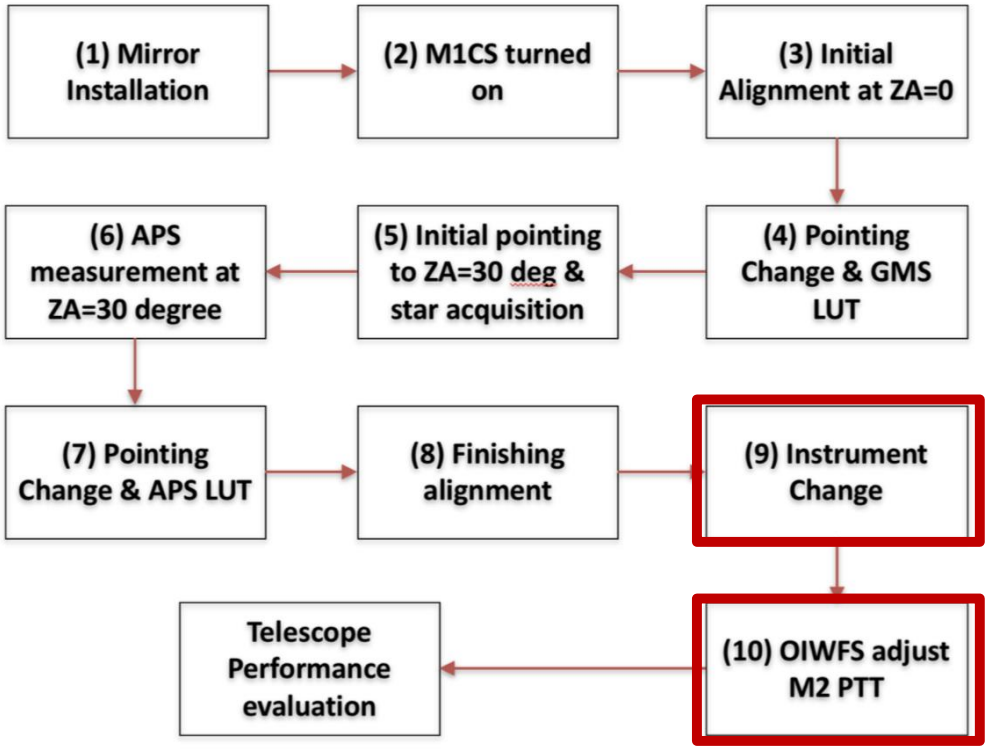


Alignment Overview & Major Assumptions



- Initial alignment at ZA=0
  - M2/M3 are aligned by GMS
  - No alignment for M1 segment and instrument, limited by installation errors.
- APS LUT
  - M1 Segment Warping Harness (ZA = 30 deg)
  - M1 Segment Piton, Tip and Tilt
  - M2 Piston, Tip and Tilt
  - M3 Tip and Tilt

Alignment Overview & Major Assumptions



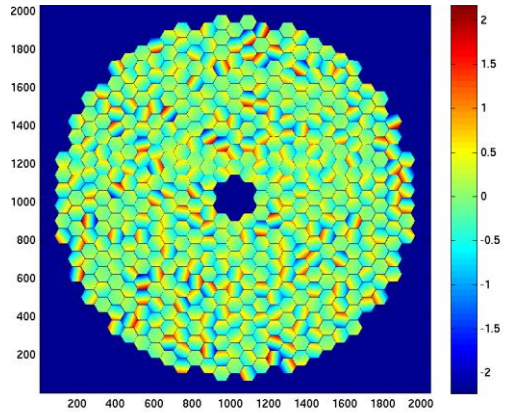
- Instrument change
  - WFOS/APS installation errors all same as NFIRAOS.
  - WFOS has the same gravity rigid-body change as APS.
  - M3 is positioned according to GMS measurement. (Not APS measurement.)
- On-Instrument WFS (OIWFS)
  - Each instrument has its own OIWFS on On-Axis.
  - Measure up to Zernike 15.
  - Adjust M2 Piston, Tip & Tilt.
  - Without it, PSSN loss of 0.01 expected.

Scope of Study

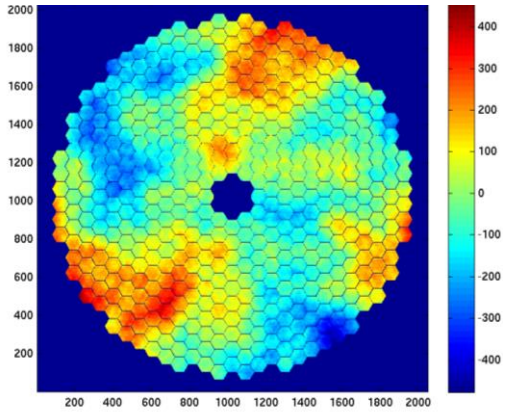
- Study includes …
  - Initial optical surface deformations.
  - Optics/Instrument gravity-dependent motions
  - Installation errors, GMS measurement errors, APS measurement errors.
  - Thermal deformation from APS calibration.
  - A potential alignment plan
- Study does NOT includes …
  - M1CS performance
  - Telescope pointing model
  - Actuator non-repeatability (hysteresis)
  - Manufacturing tolerance of telescope structure (gravity and thermal effect.)

Results at APS

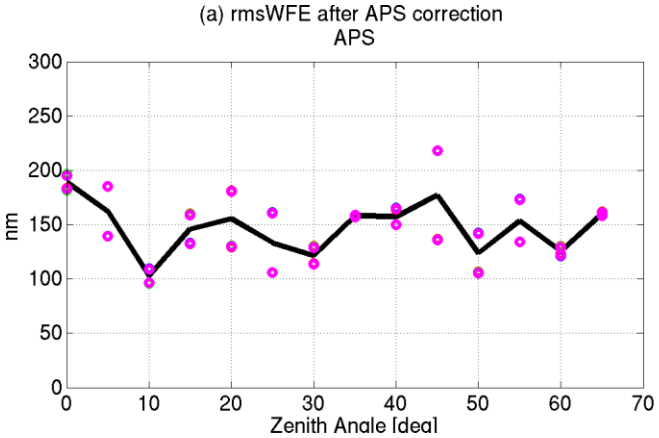
After initial alignment
rmsWFE=45000 nm, PV=444000 nm

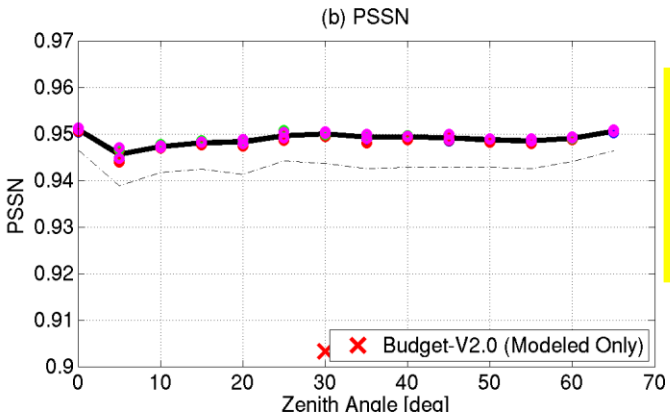


After full alignment
rmsWFE=136.0 nm, PV= 941 nm



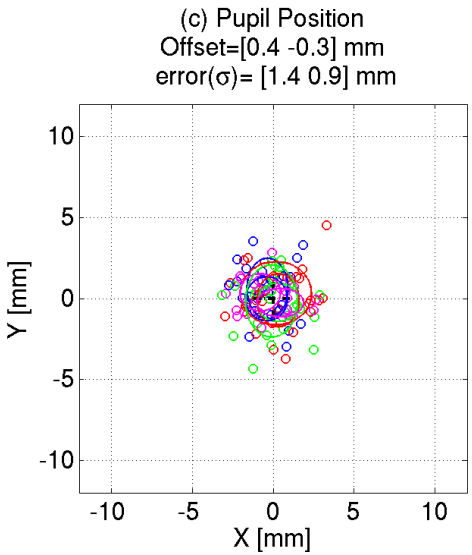
- 4 TMTs were built. (different color)
- 2 alignment processes were simulated.
- OPDs are shown at APS/OnAxis/45 deg.

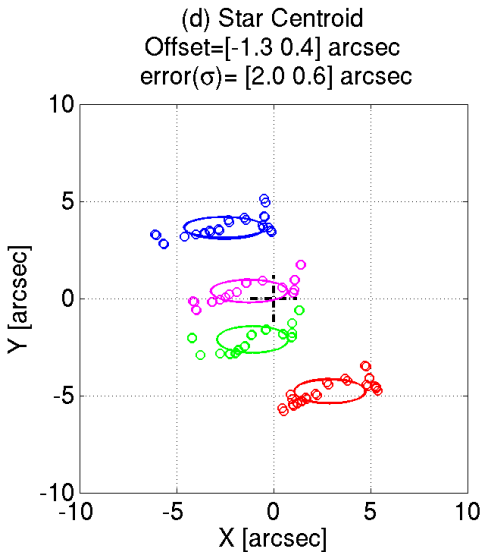


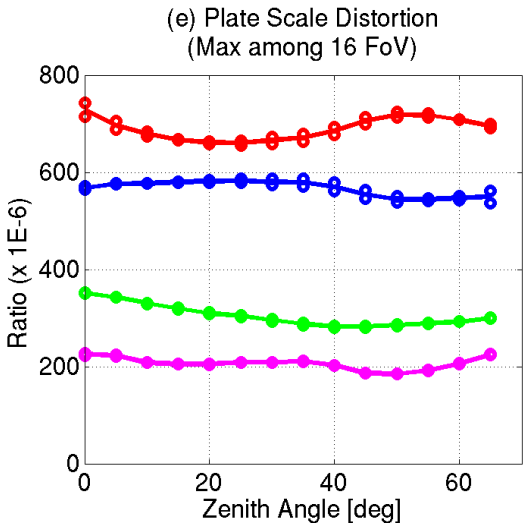


Meet the current PSSN budget with margin

Results at APS

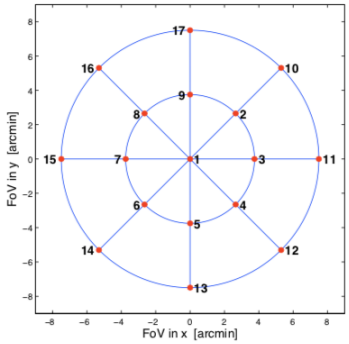






- Pupil position error is dominated by the APS pupil measurement error.
- Star centroid offset/change is mostly due to M2/M3 (No pointing model is assumed)
- Plate scale distortion is computed based on 17 FoV Sky angles

Considered Sky FoV for
Plate scale distortion calculation



Different scenarios for WFOS

	Scenario #1	Scenario #2	Scenario #3
M2	GMS LUT & APS LUT	GMS LUT & APS LUT	OIWFS
M3	GMS LUT@WFOS & APS LUT	GMS LUT@WFOS only	GMS LUT@WFOS only

What method is best and why?

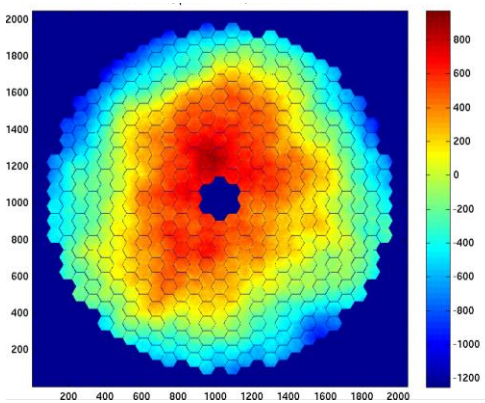
- Depends on which one is dominant; Random vs. Deterministic errors
- Random error includes Installation errors, GMS/APS measurement errors.
- Deterministic errors includes M1,M2,M3 & Instrument gravity rigid-body errors.
- Result shows random error is dominant. APS calibration does not help for M2 and M3 placement for WFOS.

Different scenarios for WFOS

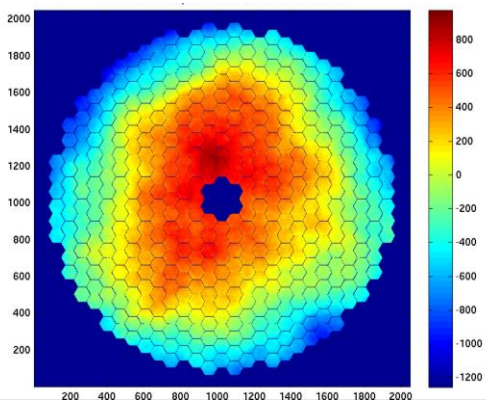
	Scenario #1	Scenario #2	Scenario #3
M2	GMS LUT & APS LUT	GMS LUT & APS LUT	OIWFS
M3	GMS LUT@WFOS & APS LUT	GMS LUT@WFOS only	GMS LUT@WFOS only

OPDs are shown at WFOS/OnAxis/45 deg for each Scenario.

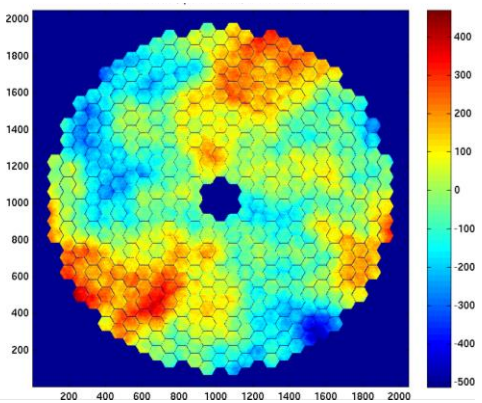
rmsWFE=404 nm, PV=2225 nm



rmsWFE=405 nm, PV=2231 nm

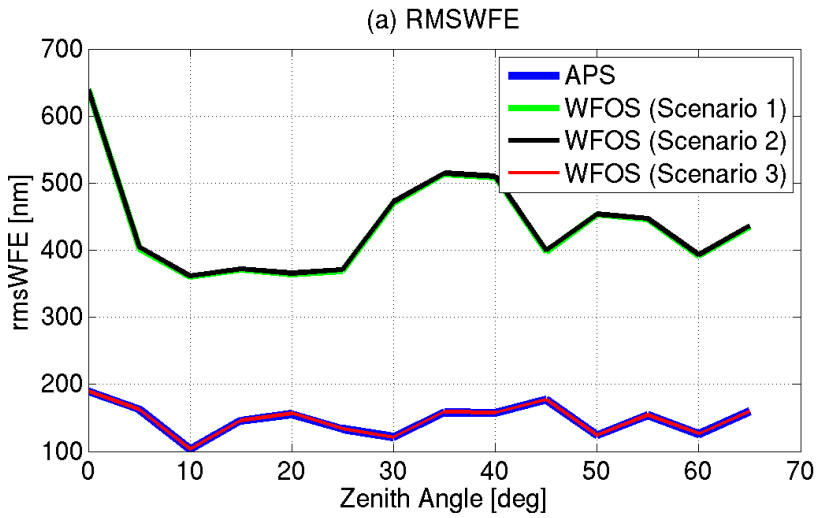


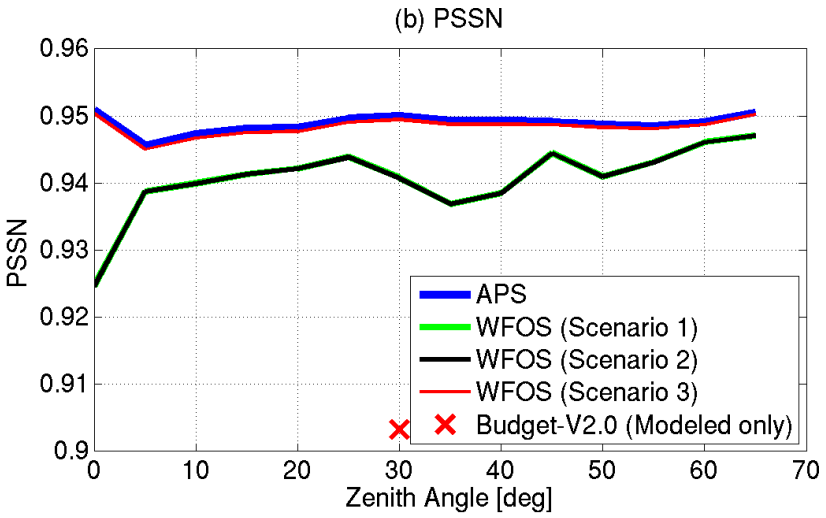
rmsWFE=138 nm, PV=983 nm

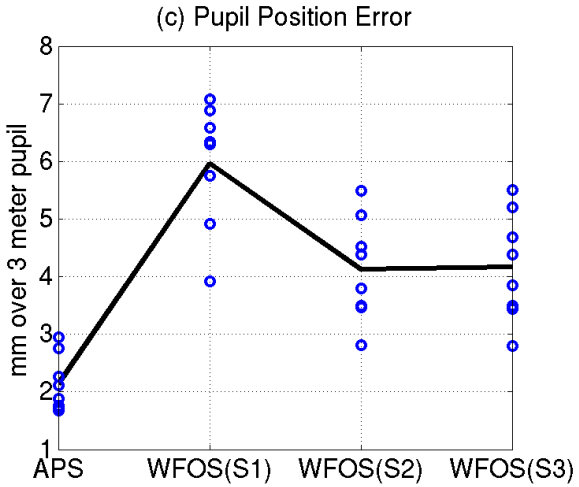


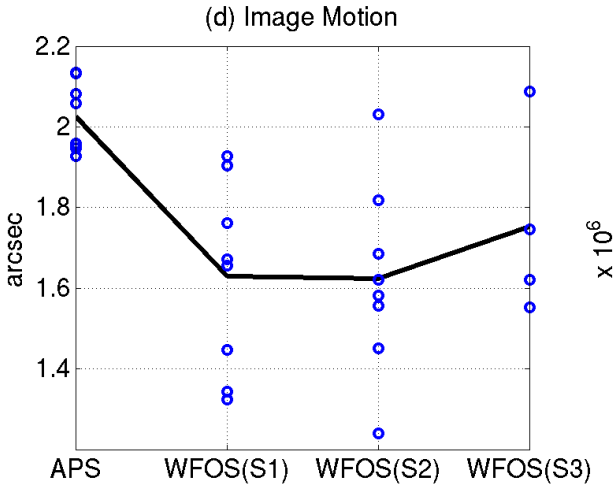
OIWFS is needed. Otherwise, large low order WFE (~400 nmRMS) is expected due to (1) instrument installation error, (2) Atmospheric noise.

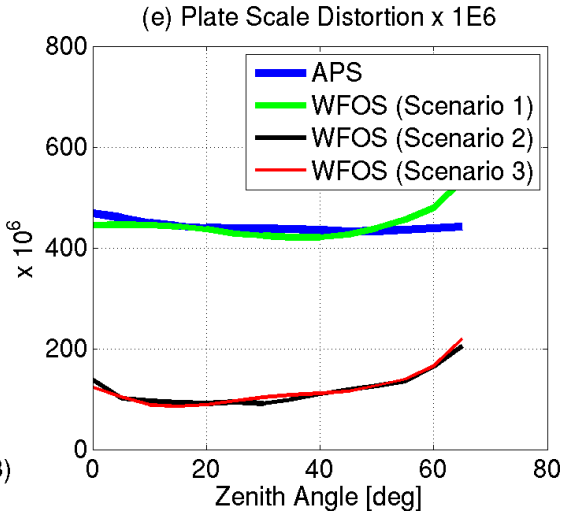
Results at WFOS











Summary & Future Work

- TMT initial alignment meets the PSSN budget.
  - Resulting PSSN is ~ 0.95 @ ZA=30 deg while the budget sum of modeled errors is 0.90327.
- Lessons learned
  - OIWFS will improve PSSN by 0.01.
  - APS measurements for M3 position makes the pupil position error worse by 30 %.
- Future work
  - Update/Include more errors
  - Validate the alignment process